Appendix F1. Supplemental Information on the Affected Environment for Fisheries

Appendix F1. Supplemental Information on the Affected Environment for Fisheries

Over 40 species of fish and invertebrates live in the Delta (Table F1-1). This impact assessment, however, is limited to species that, when considered as a group, encompass the range of potential population responses to the effects of Delta water project operations and facility construction. This appendix provides information on chinook salmon, striped bass, and American shad that supplements the information provided in Chapter 3F, "Fishery Resources". More detailed information on winter-run chinook salmon, delta smelt, Sacramento splittail, and longfin smelt is presented in Appendix F2, "Biological Assessment: Impacts of the Delta Wetlands Project on Fish Species".

Chinook Salmon

Status

Four runs of chinook salmon (*Oncorhynchus tshawytscha*) inhabit the Sacramento-San Joaquin River system: fall, late fall, winter, and spring. Timing of migration is an inherent characteristic of each run (Figure 3F-1 in Chapter 3F), modified by response to river temperature and flow.

The abundance of salmon produced from in-river spawning has declined over the last 30 years (Figure F1-1). The decline is most apparent for the winter run, currently listed as endangered under the California and federal Endangered Species Acts (see Appendix F2 for detailed discussion). Hatchery production has augmented fall-run populations so that escapement of fall-run adults has not continued to decline (Figure F1-1). Hatchery production has also contributed to spring-run populations.

Life History

Adult chinook salmon return from the ocean to spawn in the upstream reaches of the major tributaries to the Sacramento and San Joaquin Rivers. Eggs are deposited in gravel nests and fry emerge after incubating about 3 months. Juvenile chinook salmon move out of upstream spawning and rearing areas into downstream habitats in response to many factors, including inherited behavior, habitat availability, flow, competition for space and food, and water temperature. The number of juveniles that move and the timing of movement are highly variable.

In general, juvenile salmon rear in the riverine environment until becoming smolts (smolts are juveniles that are physiologically ready to enter seawater). As the young fish become smolts, they begin downstream migration to the ocean. Chinook salmon spend 2-7 years in the ocean before reaching sexual maturity and returning to their natal rivers to spawn. Most chinook salmon produced in the Sacramento River return to spawn after 3-4 years.

Adult Migration. The Delta and Bay serve as an immigration path and holding area for chinook salmon returning to their natal rivers to spawn. The four runs of chinook salmon migrate up the Sacramento River, and fall-run salmon migrate up the San Joaquin River and other Delta tributaries.

Adult chinook salmon, having arrived in the Bay, follow the salinity gradient through the Bay to the western Delta (U.S. Fish and Wildlife Service [USFWS] 1987). Once in fresh water, adults use their olfactory sense to discriminate between the waters of their home stream and those of other streams. Sacramento River chinook salmon migrate primarily up the mainstem Sacramento River, although some fish use the tributaries of the Mokelumne River and enter the Sacramento River through Georgiana Slough or the Delta Cross Channel (DCC).

Juvenile Rearing and Emigration. The Sacramento River channel (including Steamboat and Sutter Sloughs) is the most direct route for chinook salmon juveniles migrating through the Sacramento River side of the Delta. The DCC and Georgiana Slough draw flow and juvenile chinook salmon from the Sacramento River into the central Delta (Figure 4-6 in Appendix F2). The San Joaquin River channel is the most direct route for chinook salmon entering the San Joaquin River side of the Delta. Old River near Mossdale draws flow and juvenile chinook salmon from the San Joaquin River toward the intakes of the Central Valley Project (CVP) and State Water Project (SWP) export facilities.

Emigrating juvenile chinook salmon are found in the Delta and Bay throughout the year, primarily from about October through June (Figure 3F-1 in Chapter 3F). Smolts migrate through the Delta quickly, generally moving at 5-15 miles per day, approaching the higher rate as the season progresses (Wickwire and Stevens 1971). Smolts may depend on the Delta and Bay as transient rearing habitat during emigration through the system to the ocean.

The estuary provides an abundant food supply; shallow low-velocity habitat; and prior to May and June, generally good temperatures for growth. Juveniles may rear in the Delta for several weeks or months before becoming smolts. Timing of emigration through the Delta is partially dependent on race. (Schaffter 1980, Cannon 1982, Kjelson et al. 1982, USFWS 1987.)

The abundance of juveniles in the estuary relative to the total population appears to depend on river discharge (USFWS 1987). Storm events and the resulting high flows cause movement of substantial numbers of juvenile chinook salmon to downstream habitats. In general, juvenile abundance in the Delta increases as flow increases (Figure 4-3 in Appendix F2) (USFWS 1993). Because rearing occurs primarily in fresh water, higher discharge also extends the rearing habitat farther down the estuary.

The fall run constitutes about 90% of all spawners in the Sacramento-San Joaquin River system and, consequently, the most abundant juveniles in the Delta are fall-run progeny. Smolt migration is more regular than migration of presmolt juveniles. Sacramento River fall-run smolts emigrate primarily in April, May, and June (USFWS 1987, 59 FR 810). The percentage of outmigrants varies annually, especially during April and June. San Joaquin fall-run fish migrate about 1 month earlier, generally during April and May (California Department of Fish and Game [DFG] 1987a).

Factors Affecting Abundance

The primary human activities influencing chinook salmon abundance have occurred upstream of the Delta. Delta diversions, however, have increased mortality of chinook salmon.

Upstream Factors. Red Bluff Diversion Dam (RBDD) is considered one of the primary causes of reduced chinook salmon abundance in the Sacramento River. RBDD is a barrier to upstream-migrating adults that prevents and delays upstream passage (USFWS 1988, Hallock et al. 1982). Annual loss of juvenile chinook salmon to diversion at RBDD is estimated at 1% of the total migrating population (USFWS 1988). Losses of juvenile chinook salmon to predation at RBDD have been estimated to range from 29% to 77% of the migrating population (Hallock 1983).

The expected monthly survival of eggs and alevins (larval salmon that have not yet emerged from the gravel) begins to decline substantially at water temperatures above 57°F (Figure 4-4 in Appendix F2). Eggs are not expected to survive water temperatures exceeding 61°F (Healy 1979). Deleterious temperatures during spawning, incubation, and early rearing periods reduce chinook salmon survival in the Sacramento and San Joaquin Rivers and their tributaries. The effect of water temperature has been worsened by blockage of upstream passage to cooler habitats and reservoir operations that release warm water and reduce flow in the spawning and rearing areas.

Metals from Iron Mountain Mine on the Sacramento River and mines on other tributaries contribute to chinook salmon mortality. Also, release of anoxic water and associated toxic materials from reservoirs may reduce survival.

Upstream diversions are primarily agricultural withdrawals, but municipal diversions also occur. Chinook salmon juveniles are subject to entrainment in diversions throughout the year, especially during the irrigation season from April through October.

Delta Water Temperature. Temperature is a primary factor influencing the survival of chinook salmon in the Delta, especially during May and June (Kjelson et al. 1989a). Survival of juveniles begins to decline substantially at temperatures above 66°F (Figure 4-4 in Appendix F2). Juvenile growth rate declines at temperatures exceeding 60°F, depending on food availability and other factors (Figure 4-4 in Appendix F2). Reduced growth rates can be detrimental, resulting in increased freshwater residence or smaller size at ocean entry, factors that may reduce survival. Survival of juvenile fall-run chinook salmon during migration though the Delta appears to decline when water temperature exceeds 60°F (Kjelson et al. 1989b, USFWS 1992) (Figure 4-5 in Appendix F2). During migration of other runs (e.g., winter run) through the Delta, water temperature is generally below 60°F, and juveniles may not experience the magnitude of loss that fall-run juveniles have experienced (USFWS 1993).

Delay of Adult Migration through the Delta. The most direct routes upstream through the Delta during adult migration to spawning areas are the Sacramento River and San Joaquin River channels (Figure 4-6 in Appendix F2). If the water mass in the lower San Joaquin River is primarily Sacramento River water, adults seeking upstream routes may be attracted into the San Joaquin River part of the Delta and migration may be delayed until they find their way back to the Sacramento River (Hallock et al. 1970). Chinook salmon from the San Joaquin and Mokelumne Rivers may also be confused and delayed by the presence of Sacramento River water in the central and south Delta.

Sacramento River water enters the lower San Joaquin River through the DCC, Georgiana Slough, and Threemile Slough and at the confluence of the Sacramento and San Joaquin Rivers. The volume of Sacramento River water drawn into the lower San Joaquin River is affected by diversions from and inflow to the Delta east of the Sacramento River, position of the DCC gates, tidal exchange patterns, and Sacramento River discharge.

The effect of delay on spawning condition depends on duration of delay and condition of females during the spawning migration. Delays during migration through the Delta have not been shown to affect spawning success. Adverse effects on fall-run and late fall-run spawning success would be difficult to detect. Winter- and spring-run chinook salmon females may not be affected because they usually pass through the Delta in green condition (i.e., before eggs mature), and the eggs ripen months after the salmon arrive in their natal spawning area (Richardson and Harrison 1990).

Delta Cross Channel and Georgiana Slough Effects on Juvenile Migration. As stated above, the most direct routes through the Delta for Sacramento River chinook salmon are the Sacramento River channels. Juveniles are drawn along an alternate route via the DCC and Georgiana Slough (Figure 4-6 in Appendix F2), where migration is delayed and losses to diversions and predation increase. At Sacramento River temperatures below 67°F, juvenile chinook salmon drawn through the DCC and Georgiana Slough survive at a lower rate than juveniles continuing down the Sacramento River.

The proportion of Sacramento River volume drawn into the DCC depends on DCC gate position and Sacramento River discharge (Figure 4-7 in Appendix F2). Juvenile chinook salmon appear to enter Georgiana Slough and the DCC in numbers proportional to the amount of Sacramento River flow transferred into the channels, although the proportion varies with flood and ebb tide (Schaffter 1980, USFWS 1987, Hood 1990). Fish behavior, tidal stage, and other factors probably influence the relationship.

With the DCC gates open, survival of hatchery-reared fall-run chinook salmon released in the Sacramento River upstream of the DCC and Georgiana Slough is lower than the survival of fish released in the Sacramento River downstream of Georgiana Slough (USFWS 1987). Some of the fish released upstream of the DCC are drawn into the DCC and Georgiana Slough and move into the lower San Joaquin River. Migration of fall-run juveniles via the DCC and Georgiana Slough exposes juveniles to increased predation, higher temperatures, more agricultural diversions, and complex channel configurations (potentially delaying seaward migration). Juvenile salmon of other runs may be similarly affected.

When the proportion of Sacramento River flow drawn into the DCC and Georgiana Slough was high (greater than 60%) and the DCC gates were open, survival of hatchery-reared juvenile fall-run chinook salmon released above the DCC was about 50% lower than survival of juveniles released below Georgiana Slough. When the DCC gates were closed, only Georgiana Slough drew water out of the Sacramento River and survival was similar for the two release locations (USFWS 1987).

During spring 1989, survival of hatchery-reared juvenile fall-run salmon was estimated during relatively constant river flow (about 10,000 cfs in May and 13,000-14,000 cfs in June) at variable temperatures (60°F-62°F in May and 67°F-73°F in June) and fish release locations (Kjelson et al. 1990). Survival of juveniles released above the DCC (gates open) was lower than survival of juveniles released below Georgiana Slough; survival of juveniles released below Georgiana Slough was lower than survival of juveniles released in Steamboat and Sutter Sloughs. Juvenile chinook salmon released below Georgiana Slough may be carried upstream by tidal currents and drawn into the DCC or Georgiana Slough, accounting for reduced survival rates relative to survival rates of juveniles released in Steamboat and Sutter Sloughs. Survival of hatchery-reared fall-run juvenile salmon is highest for those migrating via Steamboat and Sutter Sloughs because the juvenile salmon avoid possible diversion through the DCC and Georgiana Slough.

Agricultural diversions may contribute to the difference in survival between chinook salmon migrating through the Delta via the Sacramento River and those migrating via the DCC and Georgiana Slough (USFWS 1987). Juvenile chinook salmon drawn into the DCC and Georgiana Slough are exposed to more agricultural diversions for a longer time than juveniles continuing down the Sacramento River. High agricultural diversions generally occur during late spring and summer, coinciding with juvenile fall-run migration (California Department of Water Resources [DWR] 1993). Agricultural diversions also occur during winter and can be substantial during drier years when water is needed for salt leaching and weed control.

Although increased predation has not been documented for juvenile chinook salmon migrating via the DCC and Georgiana Slough, the longer and more complex migration route may increase exposure to predators. Abundance of Sacramento squawfish and striped bass, major predators of juvenile chinook salmon, is highest (but not necessarily coincident with significant feeding periods) in the Delta during late winter and early spring (Pickard et al. 1982).

The longer and more complex migration route for smolts migrating through the DCC and Georgiana Slough may also delay migration. Delayed migration may reverse smoltification (the process of juveniles becoming adapted to seawater) and reduce survival.

Old River. Data from the release of tagged juvenile chinook salmon indicate that juveniles from the San Joaquin River that are diverted into upper Old River have greater mortality than those migrating down the mainstem San Joaquin River (USFWS 1993). Exposure to diversions (agricultural and CVP and SWP export) may increase mortality. Although uncertainty remains in understanding juvenile chinook salmon survival in the San Joaquin River side of the Delta, a barrier on Old River in conjunction with increased San Joaquin River inflow and reduced exports appears to increase juvenile chinook salmon survival.

Effects of Lower San Joaquin River Flows on Juvenile Migration. Juvenile winter-run migrating via the DCC and Georgiana Slough and juveniles from the Mokelumne and San Joaquin Rivers eventually enter the lower San Joaquin River (Figure 4-6 in Appendix F2). Hatchery-reared fall-run juveniles released at several Delta locations experienced the lowest survival rate when released south of the San Joaquin River in Old River near Holland Tract (USFWS 1987). The lower survival rate probably resulted from migration into the south Delta. Predation in Clifton Court Forebay (possibly exceeding 85%) and at the SWP and CVP fish protection facilities (about 15%) and entrainment in diversions substantially reduce survival of juvenile chinook salmon in the south Delta.

Reverse flow in the lower San Joaquin River may reduce the survival of juvenile chinook salmon migrating through the Delta (USFWS 1993). High rates of diversion relative to inflow cause flows to reverse. For juvenile chinook salmon released at Ryde on the Sacramento River, temperature-corrected survival was lower when net flows out of the central Delta (a calculated flow known as QWEST [DWR 1993]) were low or reversed (Figure 4-8 in Appendix F2).

When flow in upper Old River is less than the export rate at the SWP and CVP Delta pumping facilities, or when Old River near Mossdale is closed with a barrier, flows in Old and Middle Rivers north of the SWP and CVP pumping facilities are reversed (i.e., toward the south). Reverse flows in Old and Middle Rivers occur most of the time and may have an adverse effect on juvenile salmon migrating through the central Delta, including Sacramento River salmon, that have been drawn through the DCC and Georgiana Slough (USFWS 1992). Information is currently unavailable to determine the effect of flow in Old and Middle River on survival of juvenile chinook salmon and whether survival changes with the magnitude of southerly flow.

Diversions and Entrainment. Diversions may result in mortality not attributable to entrainment losses. Diversion-caused mortality of juvenile chinook salmon may be a function of lower San Joaquin River flow effects discussed in the previous section. For juvenile chinook salmon in the Sacramento River, those salmon drawn into the DCC and Georgiana Slough are most affected by diversions and related factors (Kjelson et al. 1989a).

Agricultural diverions are highest during late spring and summer (DWR 1993). Diversion at the CVP and SWP pumps, however, is high during most of the year and entrainment losses of juvenile chinook salmon may be substantial (DWR 1993). Total entrainment loss may exceed several hundred thousand juvenile chinook salmon, including substantial losses to predation (assuming about 75% at the SWP and 15% at the CVP) and 20%-40% loss attributable to the salvage procedure (about 70% screening efficiency and additional losses to handling and trucking) (DFG 1992a). Screening efficiency is a function of fish length and channel approach velocity and ranges from 63% to over 77% for smolts at the SWP pumps (Brown and Greene 1992). Efficiency at the CVP pumps is assumed to be about 75%.

Although the Sacramento River produces more than 80% of the fall-run chinook salmon, the majority of juveniles salvaged at the CVP and SWP export pumps are from the San Joaquin River (i.e., about 90% of the juvenile chinook salmon salvaged at the CVP pumps are San Joaquin River stock) (DFG 1987b).

Most juvenile chinook salmon from the Sacramento River delta that are entrained at the CVP and SWP pumps probably migrated via the DCC and Georgiana Slough. Juveniles that continue down the Sacramento River to the west Delta are less likely to be entrained in SWP and CVP diversions. Tidal currents dominate Sacramento River hydrodynamics at the junction of Threemile Slough and the lower San Joaquin River, except during periods of very high river discharge. Most juvenile salmon that avoid the DCC and Georgiana Slough (especially smolts) continue migrating toward the ocean, possibly following the salinity gradient.

Movement of juveniles up the lower San Joaquin River from the west Delta and into the south Delta may occur when net reverse flow creates conditions that disorient the migrants; however, net flow volume is usually less than 1% of tidal volume in the lower San Joaquin River. Some of the tagged juvenile chinook salmon released in the San Joaquin River at Jersey Point in 1989 were recovered at the Banks pumping facility (Kjelson et al. 1990). The juvenile salmon, possibly disoriented by transport, were released on flood tide that may have moved them farther upstream, where the influence of cross-Delta flow increases.

Sport and Commercial Fishing. Sport and commercial fishing may reduce adult chinook salmon escapement (i.e., return of adults to spawn) to the rivers by 35%-85% (Pacific Fishery Management Council 1989, DFG 1989). Most of the catch occurs in the ocean fishery. Ocean and river fishing regulations have been implemented to restrict sport and commercial fishing relative to historical regulations.

Summary

Habitat degradation has reduced chinook salmon populations. Major factors affecting the population decline are blockage of adult passage to suitable spawning and rearing areas and lethal water temperatures during egg incubation and early rearing. Other factors that may impede recovery to former abundance include entrainment loss to diversions, increased predation, toxic discharge to the rivers, diversion off the primary juvenile migration path through the Delta, and ocean fishing.

Striped Bass

Status

Adult striped bass (*Morone saxatalis*) abundance has declined over the last 30 years (Figure F1-2). The population has declined from over 1.5 million adult bass in the late 1960s to about 0.5 million bass in 1992. The decline in adult abundance resulted primarily from reduced young-of-year abundance (Figure F1-2).

Life History

Adult striped bass can be found in the Delta and Bay environment throughout the year. They begin concentrating primarily in San Pablo and Suisun Bays in fall and move into the Delta and up the Sacramento River during winter and early spring (DFG 1987c). The estimated annual spawning distribution varies each year, and the portion of the stock spawning in the Sacramento River upstream of the Delta has ranged from 46% to 66% during May and June (DFG 1987a). The remaining portion of the population spawns in the San Joaquin River between Antioch and Venice Island during April and May. Adults usually leave fresh water by June or July, but most remain in the Bay.

Striped bass spawn in fresh water, with optimum spawning success occurring at salinity of less than 1 part per thousand (ppt) (DFG 1987c). The spawning area in the Delta is generally limited by the salinity and is usually located just downstream of Antioch Point to above Venice Island (or farther upstream in wet years), where agricultural drainage salt concentrations are high.

Semibuoyant eggs are broadcast-spawned in open water, drift with the current, and hatch in about 2 days (DFG 1987c). Newly hatched larvae drift with the current, and Sacramento River larvae generally reach the

Delta within a few days. Newly hatched larvae are carried downstream to the upstream edge of the entrapment zone (i.e., about 2-ppt salinity) (Figure 4-10 in Appendix F2). The location of the entrapment zone depends on Delta outflow. High outflow moves the entrapment zone into Suisun Bay or farther downstream. Lower flows allow the entrapment zone to remain in the Delta.

Striped bass larvae begin feeding at a length of 5-6 millimeters (mm) and grow to about 38 mm by late July or August (Turner 1987). Their initial diet consists of invertebrates, including Cladocera (*Bosmina* and *Daphnia*) and Copepoda (*Eurytemora* and *Sinocalanus*), with copepods dominating the diet of 7- to 11-mm larvae. When larvae exceed lengths of 11 mm, copepods continue to be important, but the mysid *Neomysis* becomes the primary food organism (DFG 1987c).

Factors Affecting Abundance

Year-class abundance of striped bass is assumed to depend on the environmental conditions experienced by the eggs and young fish. The primary human-caused factors influencing abundance of young striped bass include entrainment in Delta diversions, reduced Delta outflow, and discharge of toxic materials into rivers tributary to the Delta and into the estuary. Other factors affecting striped bass abundance include reduced prey availability, competition with or predation by introduced species, and reduced egg production (Brown 1987a). Adult abundance is also reduced by sport fishing and illegal fishing.

Delta Outflow. Delta outflow is highly variable across years; seasonally; and at times, weekly. In general, month-to-month outflows in any given year are highly autocorrelated (i.e., flow during one month is related to flow the previous month), whereas year-to-year outflows are not (i.e., flows during one year are not related to flows the previous year). This generally means that in wet years, high outflows occur across several months (Herbold et al. 1992). In any given year, outflow has ranged from less than 10 million acre-feet (MAF) each year to over 50 MAF each year.

Although dependent on the natural hydrology of the Sacramento-San Joaquin River system, the timing and volume of Delta outflow have been substantially modified by changes in system characteristics (i.e., channelization and flood control projects) and by operations of water project facilities (i.e., reservoirs and diversions) (Herbold et al. 1992). Channelization and flood control projects (not including reservoir storage) enable water to move more quickly through the Delta. Storage results in reduction of peak flows and changes in the timing of water movement down the rivers. Consumptive diversions remove water from the system.

Compared with natural conditions, water projects have increased summer and fall outflow and reduced winter and spring outflow (Herbold et al. 1992). Total annual Delta outflow may be reduced by 50%-60% of the outflow expected in the absence of storage and diversions, with less proportional change in wet years and more in dry years.

X2 (the location relative to the Golden Gate Bridge of the 2-ppt isohaline, or about 3,000 microsiemens (μS) electrical conductivity [EC]) is generally considered the upstream boundary of the entrapment zone (San Francisco Estuary Project 1993). The location of X2 in the estuary is a function of Delta outflow volume; as outflow increases, X2 moves farther downstream.

When X2 is in Suisun Bay, the proportion of the striped bass population in the Delta is lower than when X2 is in the Delta (Figure F1-3) (DFG 1992b). The mechanism of distribution (i.e., whether outflow transports the larvae downstream or larvae actively maintain their location relative to the entrapment zone) is not known.

Survival of young bass in the Delta depends on Delta outflow and on the location of X2 (Figure F1-3). Survival of young-of-year striped bass is highest during periods of high flows that distribute most of the population downstream of the Delta. Location of the entrapment zone downstream of the Delta in Suisun Bay may provide optimum habitat for larvae and juvenile striped bass.

High outflow may be more effective than low outflow in transporting striped bass eggs and larvae to the entrapment zone and away from the effects of Delta diversions (DFG 1992b). In addition, high outflow may dilute toxic materials and increase turbidity that could reduce predation.

Diversions and Entrainment Loss. Survival of striped bass in the Delta appears to have declined after 1970 (DFG 1992b). The reduction in striped bass survival after 1970 may be attributed to increased diversion (the SWP Delta pumping facilities began substantial diversion in 1970).

Striped bass are most vulnerable to entrainment-related mortality from April to mid-July during their egg, larval, and early juvenile stages (Figure F1-4) (DFG 1987c). The magnitude of entrainment depends on population density and distribution, Delta inflow and outflow, and the volume and timing of agricultural diversions and Delta exports.

Decreasing inflow to the Delta increases the proportional loss of fish to diversions, including CVP and SWP export pumping, power plant diversions of cooling water, and agricultural diversions located throughout the Delta and the Sacramento and San Joaquin River systems. Relative losses may increase with decreasing inflow because fairly constant volumes are diverted each year and the proportion of flow (and fish) diverted varies with flow rate (Stevens and Miller 1983).

More importantly, the proportion of striped bass in the Delta is greater during low-flow years (Figure F1-3). In the Delta, young bass are more vulnerable to entrainment in diversions. Entrainment loss of striped bass larger than 18 mm at the John E. Skinner Delta Fish Facility for the SWP pumps was shown to be significantly related to QWEST, combined exports of the CVP and SWP pumps, total striped bass abundance, and mean size of striped bass (Wendt 1987). Thus, increasing exports and reducing QWEST increases the entrainment loss of striped bass larger than 18 mm.

The annual rate of egg, larval, and juvenile mortality resulting from entrainment in SWP and CVP exports is significant, exceeding millions of fish each year (DFG 1992b). Other diversions that entrain striped bass include Pacific Gas and Electric Company's (PG&E's) Pittsburg and Contra Costa power plants; more than 1,800 agricultural diversions; and miscellaneous municipal and industrial diversions. Although some biologists believe that mortality from entrainment alone cannot explain the decline in the striped bass population (Brown 1987a), entrainment loss of juvenile bass may affect future adult abundance (Turner 1987, Kohlhorst et al. 1992).

Lower San Joaquin River. Rates of diversion in the southern Delta that exceed inflows from the San Joaquin River and eastside tributaries often cause net reverse flow in the lower San Joaquin River and other Delta channels (e.g., negative QWEST). Net reverse flow may transport striped bass eggs and larvae toward the SWP and CVP export facilities and may alter natural migration patterns of larvae and early juveniles. The location of young-of-year striped bass in the estuary may determine the effect of other factors, including lower San Joaquin River flow.

Toxic Substances. Agricultural chemicals (including pesticides and herbicides), heavy metals, petroleum-based products, and other waste materials toxic to aquatic organisms enter the estuary through nonpoint runoff, agricultural drainage, and municipal and industrial discharges. Recent bioassays by the Central Valley Regional Water Quality Control Board indicate that water in the Sacramento River is periodically toxic to larvae of the fathead minnow, a standard U.S. Environmental Protection Agency (EPA) test organism (Stevens et al. 1990), and to striped bass larvae. Toxic substances may kill larval bass and reduce their capacity to adapt to variable conditions in the estuary.

The health and survival of adult striped bass could be reduced by the presence of toxic substances in the estuary. Some adult bass have accumulated toxins in their tissues and appear to be in poor health compared with bass in other populations (Brown 1987b). Although toxic substances may reduce striped bass populations in the estuary, toxics alone are not likely to be responsible for the long-term decline in striped bass abundance; treatment and regulatory control over the discharge of toxic substances have increased greatly in recent years.

Egg Production. Since the 1970s, egg production appears to have declined by as much as 90% because the bass population is less abundant and is composed of younger fish (smaller size of female fish). Although the relationship between the number of eggs produced by the population and year-class strength is weak, the relationship is believed to be a significant factor in the decline of the striped bass (Kohlhorst et al. 1992). Although egg production may affect year-class strength, the fecundity of striped bass (e.g., over 500,000 eggs per 6-year-old female), coupled with favorable environmental conditions, provides the opportunity for substantial population increase (DFG 1987c, Striped Bass Working Group 1982).

Prey Availability. Striped bass mortality is highest during the early life stages when the fish are small. Slowed growth subjects the larvae to higher mortality rates over a longer period. Low prey density may contribute to lower growth rates. Although declines in first-year growth rates have occurred (DFG 1987c), and densities of potential prey species have decreased greatly in recent years (Obrebski et al. 1992), a relationship between prey density in the Bay-Delta environment and early striped bass growth is suspected but has not been shown. The close association between *Eurytemora* abundance and larval bass survival from 1984 to 1986 indicates a need for continued study.

Other Factors. Introduction of exotic species may also affect striped bass abundance. Competition and predation cannot be ruled out as potential factors affecting abundance; however, there has not been a consistent increase in the abundance of potential predators or competitors that could account for the decline in striped bass over the last 30 years.

Sport fishing removes 15%-30% of the adult population each year, and illegal fishing removes an unknown additional amount (DFG 1992b). Healthy fish populations can sustain significant levels of fishing mortality (probably greater than 40%); however, the decline in striped bass abundance indicates that the population is unhealthy and that fishing mortality may adversely affect the population.

Summary

An important factor affecting striped bass abundance may be the location of the young-of year population in the estuary (i.e., abundance is highest when outflow is sufficient to locate X2 in Suisun Bay during April-July). Other factors that may adversely affect the striped bass abundance include decline in the availability of major prey organisms, low population levels, entrainment in water diversions from the Delta and upstream of the Delta, introduced exotic fish and invertebrate species, and toxic substances (DFG 1992a, 1992b).

American Shad

Status

Since the early 1900s, the population of American shad (*Alosa sapidissima*)is believed to have experienced a gradual decline in abundance (DFG 1987d). The decline, however, is not supported by the young-of-year index of abundance estimated for the last 28 years, beginning in 1967.

Life History

Adult American shad immigrate to fresh water from the ocean and the Bay during March, April, and May (DFG 1987d). The adults actively feed during their migration, preying on *Neomysis* and various cladocerans (Stevens 1966). Spawning begins in May and continues into early July (DFG 1987d). After spawning, the adults leave the spawning grounds and return to the Bay and ocean by September.

The primary spawning grounds are in the upper Sacramento River and its tributaries. The northern Delta and the northern portion of Old River have also supported shad spawning (DFG 1987d). Shad broadcast-spawn their eggs and sperm into the currents, where the semibuoyant eggs sink slowly and drift with the flow. The eggs are less buoyant than striped bass eggs and tend to remain near the spawning location. Eggs hatch in 4-6 days, and as the larvae grow, they begin feeding on copepods and cladocerans. Ganssle (1966) reported *Neomysis*, copepods, larval fish, and *Corophium* to be the primary prey of young-of-year American shad.

The young shad do not continue to drift with the currents; they actively maintain their position. Shad spawned in the Sacramento River system generally rear in the tributary rivers downstream of the spawning area. Shad spawned in the Delta appear to rear primarily in the Delta. The locations of major rearing areas vary from year to year and seem to be dependent on river flow (i.e., high flows transport the eggs and larvae farther downstream) (DFG 1987d).

Most juvenile American shad emigrate from their freshwater rearing areas and enter the Bay between September and December (Stevens 1966). Timing of the seaward emigration probably depends on size (migrating juveniles are usually 5-15 cm in length), although the final exodus may be triggered by declining water temperature (Chittendon 1982). By January, most juveniles have emigrated to the ocean, but some remain in the estuary until maturity.

Factors Affecting Abundance

American shad abundance may be affected by factors similar to those discussed for striped bass. The environmental conditions experienced by the eggs and young fish may be most important in determining population abundance. Ocean conditions, however, may also be an important factor in American shad abundance. The primary human-caused factors influencing young American shad abundance include entrainment in Delta diversions, reduced Delta outflow, reduced tributary outflow, discharge of toxic materials into rivers tributary to the Delta and into the estuary, and sport fishing mortality.

Delta Outflow. Young-of-year American shad abundance during the fall midwater trawl surveys is positively correlated with Delta outflow during April-June (DFG 1987d). Mechanisms that explain increased abundance at higher outflow are unknown; however, most young-of-year shad appear to rear upstream of the Delta prior to the fall survey, and river conditions may be the primary factor affecting abundance. Delta outflow is a reflection of tributary flow. Higher river flows during April-June may enhance egg and larval survival by increasing suspension off the bottom, reducing water temperature during the early rearing period, reducing the concentration of toxic substances, increasing downstream distribution, and reducing the proportional entrainment in diversions.

Diversions and Entrainment Loss. Hundreds of thousands of American shad larvae and juvenile fish are entrained each year at the SWP and CVP export facilities (DFG 1987d). Shad spawned in the Delta are entrained as larvae and juveniles primarily during July-August. Shad spawned upstream of the Delta are entrained as juveniles primarily during November and December. Juvenile shad entrained during fall are screened more efficiently than the smaller juveniles and larvae entrained during summer. Shad survivial during salvage, however, may be low because of sensitivity to handling. Agricultural and other diversions also entrain shad larvae and juveniles.

Other Factors. Other factors affecting shad may include prey availability and presence of toxic materials. In addition, the sport fishery removes thousands of adults from the population each year. The effect of the fishery on the population is unknown.

Summary

Upstream water storage, upstream diversions, and diversions from the Delta have modified American shad habitat and may affect abundance. Upstream flows may be the most important factor affecting young-of-year abundance. Entrainment of young-of-year shad in water diversions from the Delta reduces juvenile survival.

CITATIONS

References to the Federal Register (FR) are not included in this list. FR citations in text refer to volume and page number (e.g., 59 FR 810 refers to Volume 59 of the FR, page 810).

Brown, R. L. (comp.) 1987a. 1985-1986 report of the interagency ecological studies program for the Sacramento-San Joaquin estuary. July. (AR-15/87.) California Department of Water Resources and U.S. Fish and Wildlife Service. Sacramento, CA.

Brown, R. L. 1987b. Toxics and young striped bass. (DWR Exhibit 605, Bay-Delta Hearing.) California Department of Water Resources. Sacramento, CA.

Brown, R. L, and S. Greene. 1992. Biological assessment, effects of Central Valley Project and State Water Project Delta operations on winter-run chinook salmon. October. California Department of Water Resources. Sacramento, CA.

California. Department of Fish and Game. 1987a. The status of San Joaquin drainage chinook salmon stocks, habitat conditions and natural production factors. (DFG Exhibit No. 15, State Water Resources Control Board 1987 water quality/water rights proceeding for the San Francisco Bay/Sacramento-San Joaquin Delta, Sacramento, CA.) Sacramento, CA.

__________. Department of Fish and Game. 1987b. Estimates of fish entrainment losses associated with the State Water Project and federal Central Valley Project facilities in the south Delta. (DFG Exhibit 17, Bay-Delta Hearing.) Sacramento, CA. Prepared for California State Water Resources Control Board, Bay/Delta Hearing Process, Phase I. Sacramento, CA.

__________. Department of Fish and Game. 1987c. Factors affecting striped bass abundance in the Sacramento-San Joaquin River system. (DFG Exhibit 25, Bay-Delta Hearing.) Sacramento, CA.

__________. Department of Fish and Game. 1987d. Requirements of American shad (*Alosa sapidissima*) in the Sacramento-San Joaquin River system. (DFG Exhibit 23, Bay-Delta hearing.) Sacramento, CA. Prepared for California State Water Resources Control Board, Bay/Delta Hearing Process, Phase I. Sacramento, CA.

__________. Department of Fish and Game. 1989. Winter-run chinook salmon impact analysis report: ocean and in-river sportfishery. (Memorandum: August 29, 1989.) Sacramento, CA. Prepared for California Fish and Game Commission, Sacramento, CA.

__________. Department of Fish and Game. 1992a. Revised and updated estimates of fish entrainment losses associated with the State Water Project and Federal Central Valley Project facilities in the South Delta. Sacramento, CA.

__________. Department of Fish and Game. 1992b. A re-examination of factors affecting striped bass abundance in the Sacramento-San Joaquin estuary. (State Water Resources Control Board 1992 Bay-Delta proceedings, Sacramento, CA.) Sacramento, CA.

__________. Department of Water Resources. 1993. Day flow data summaries for water years 1955-1956 through 1991-1992. Sacramento, CA.

Cannon, T. C. 1982. The importance of the Sacramento-San Joaquin estuary as a nursery area of young chinook salmon, striped bass, and other fishes. Envirosphere. Newport Beach, CA. Prepared for U.S. Department of Commerce, National Marine Fisheries Service, Southwest Region, Terminal Island, CA.

Chittendon, M. E. 1982. Responses of young American shad, *Alosa sapidissima*, to low temperatures. Transactions of the American Fisheries Society 104(4):680-685.

Ganssle, D. 1966. Fishes and decapods of San Pablo and Suisun Bays. Pages 64-94 in D. W. Kelley (ed.), Ecological studies of the Sacramento-San Joaquin estuary. Part I. (Fish Bulletin 133.) California Department of Fish and Game. Sacramento, CA.

Hallock, R. J. 1983. Effects of Red Bluff Diversion Dam on chinook salmon, *Oncorhynchus tshawytscha*, fingerlings. (Anadromous Fisheries Branch Office Report.) California Department of Fish and Game. Red Bluff, CA.

Hallock, R. J., R. F. Elwell, and D. H. Fry, Jr. 1970. Migrations of adult king salmon, *Oncorhynchus tshawytscha*, in the San Joaquin Delta. (Fish Bulletin 151.) California Department of Fish and Game. Sacramento, CA.

Hallock, R. J., D. A. Vogel, and R. R. Reisenbichler. 1982. The effect of Red Bluff diversion dam on the migration of adult radio tagged fish. (Administrative Report No. 82-8.) California Department of Fish and Game, Anadromous Fisheries Branch. Sacramento, CA.

Healey, T. P. 1979. The effect of high temperature on the survival of Sacramento River chinook (king) salmon, *Oncorhynchus tshawytscha*, eggs and fry. (Administrative Report No. 79-10.) California Department of Fish and Game, Anadromous Fisheries Branch. Sacramento, CA.

Herbold, B., A. D. Jassby, and P. B. Moyle. 1992. Status and trends report on aquatic resources in the San Francisco estuary. San Francisco Estuary Project, U.S. Environmental Protection Agency. Oakland, CA.

Herrgesell, P. L. 1993. 1991 annual report. Interagency Ecological Studies Program for the Sacramento-San Joaquin estuary. California Department of Fish and Game. Stockton, CA.

Hood, D. J. 1990. Fish abundance, size and distribution in the Sacramento River near Hood, California, in February and March 1990. U.S. Fish and Wildlife Service, Fisheries Assistance Office. Stockton, CA.

Kjelson, M. A., D. Hood, and P. L. Brandes. 1989a. Survival of chinook salmon smolts in the Sacramento River Delta during 1989. (1989 Annual Progress Report, FY89 Work Guidance.) U.S. Fish and Wildlife Service, Fisheries Assistance Office. Stockton, CA.

Kjelson, M. A., S. Greene, and P. Brandes. 1989b. A model for estimating mortality and survival of fall-run chinook salmon smolts in the Sacramento River Delta between Sacramento and Chipps Island. U.S. Fish and Wildlife Service, Stockton, CA.

Kjelson, M. A., P. F. Raquel, and F. W. Fisher. 1982. Life history of fall run juvenile chinook salmon (*Oncorhynchus tshawytscha*) in the Sacramento-San Joaquin estuary, California. Pages 393-411 in U. S. Kennedy (ed.), Estuarine comparisons. Academic Press. New York, NY.

Kjelson, M. A., B. Loudermilk, D. Hood, and P. Brandes. 1990. The influence of San Joaquin River flow, Central Valley and State Water Project exports and migration route on fall-run chinook smolt survival in the southern Delta during spring of 1989. (WQCP-USFWS-4.) U.S. Fish and Wildlife Service, Fisheries Assistance Office. Stockton, CA.

Kohlhorst, D. W., D. E. Stevens, and L. W. Miller. 1992. A model for evaluating the impacts of freshwater outflow and export on striped bass in the Sacramento-San Joaquin estuary. California Department of Fish and Game. Stockton, CA.

Mills, T. J., and F. Fisher. 1993. Central Valley anadromous sport fish annual run-size, harvest estimates, and population trends, 1967 through 1991. Preliminary draft. June. (Inland Fisheries Technical Report.) California Department of Fish and Game. Sacramento, CA.

Obrebski, S., J. J. Orsi, and W. J. Kimmere. 1992. Long-term trends in zooplankton distribution and abundance in the Sacramento-San Joaquin estuary in California. (FS/BIO-IATR/92-32, Technical Report 32.) California Department of Water Resources. Sacramento, CA. Prepared for Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary, Stockton, CA.

Pacific Fishery Management Council. 1989. Review of 1988 ocean salmon fisheries. Portland, OR.

Pickard, A., A. Grover, and F. A. Hall, Jr. 1982. An evaluation of predator composition at three locations on the Sacramento River. (Technical Report 2.) California Department of Water Resources. Sacramento, CA. Prepared for Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary, Stockton, CA.

Richardson, T. H., and P. Harrison. 1990. An analysis of fish and wildlife impacts of Shasta Dam water temperature control alternatives. U.S. Fish and Wildlife Service, Fish and Wildlife Enhancement. Sacramento, CA. Prepared for U.S. Bureau of Reclamation, Sacramento, CA.

San Francisco Estuary Project. 1993. Managing freshwater discharge to the San Francisco Bay/Sacramento-San Joaquin Delta estuary: the scientific basis for an estuarine standard. San Francisco, CA.

Schaffter, R. G. 1980. Fish occurrence, size, and distribution in the Sacramento River near Hood, California, during 1973 and 1974. (Administrative Report No. 80-3.) California Department of Fish and Game. Sacramento, CA.

Stevens, D. E. 1966. Distribution and food habits of the American shad, *Alosa sapidissima*, in the Sacramento-San Joaquin Delta. Pages 97-105 in J. L. Turner and D. W. Kelley (eds.), Ecological studies of the Sacramento-San Joaquin Delta. Part II. Fishes of the Delta. (Fish Bulletin 136.) California Department of Fish and Game. Sacramento, CA.

Stevens, D. E., and L. W. Miller. 1983. Effects of river flow on abundance of young chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento-San Joaquin River system. North American Journal of Fisheries Management 3:425-437.

Stevens, D. E., L. W. Miller, and B. C. Bolster. 1990. Report to the Fish and Game Commission: a status review of the delta smelt (*Hypomesus transpacificus*) in California. (Candidate Species Status Report 90-2.) California Department of Fish and Game. Stockton, CA.

Striped Bass Working Group. 1982. The striped bass decline in the San Francisco Bay-Delta estuary. California State Water Resources Control Board. Sacramento, CA.

Turner, J. L. 1987. Effects of geographic distribution of larval striped bass in determining year class size of striped bass in the Sacramento-San Joaquin estuary. (USBR Exhibit 100, Bay-Delta Hearing.) EXOS, Environmental and Energy Consultants. Sacramento, CA. Prepared for U.S. Bureau of Reclamation, Sacramento, CA.

U.S. Fish and Wildlife Service. 1987. The needs of chinook salmon, *Oncorhynchus tshawytscha*, in the Sacramento-San Joaquin estuary. (USFWS Exhibit 31, Bay-Delta Hearing.) Sacramento, CA. Prepared for California State Water Resources Control Board 1987 Water Quality/Water Rights Proceeding on the San Francisco Bay/Sacramento-San Joaquin Delta, Sacramento, CA.

_________. 1988. Fish passage action program for Red Bluff diversion dam, final report on fishing investigations. (Report No. FRI/FAO-88-19.) Red Bluff, CA.

_________. 1992. Abundance and survival of juvenile chinook salmon in the Sacramento-San Joaquin estuary. (1991 Annual Progress Report.) Stockton, CA.

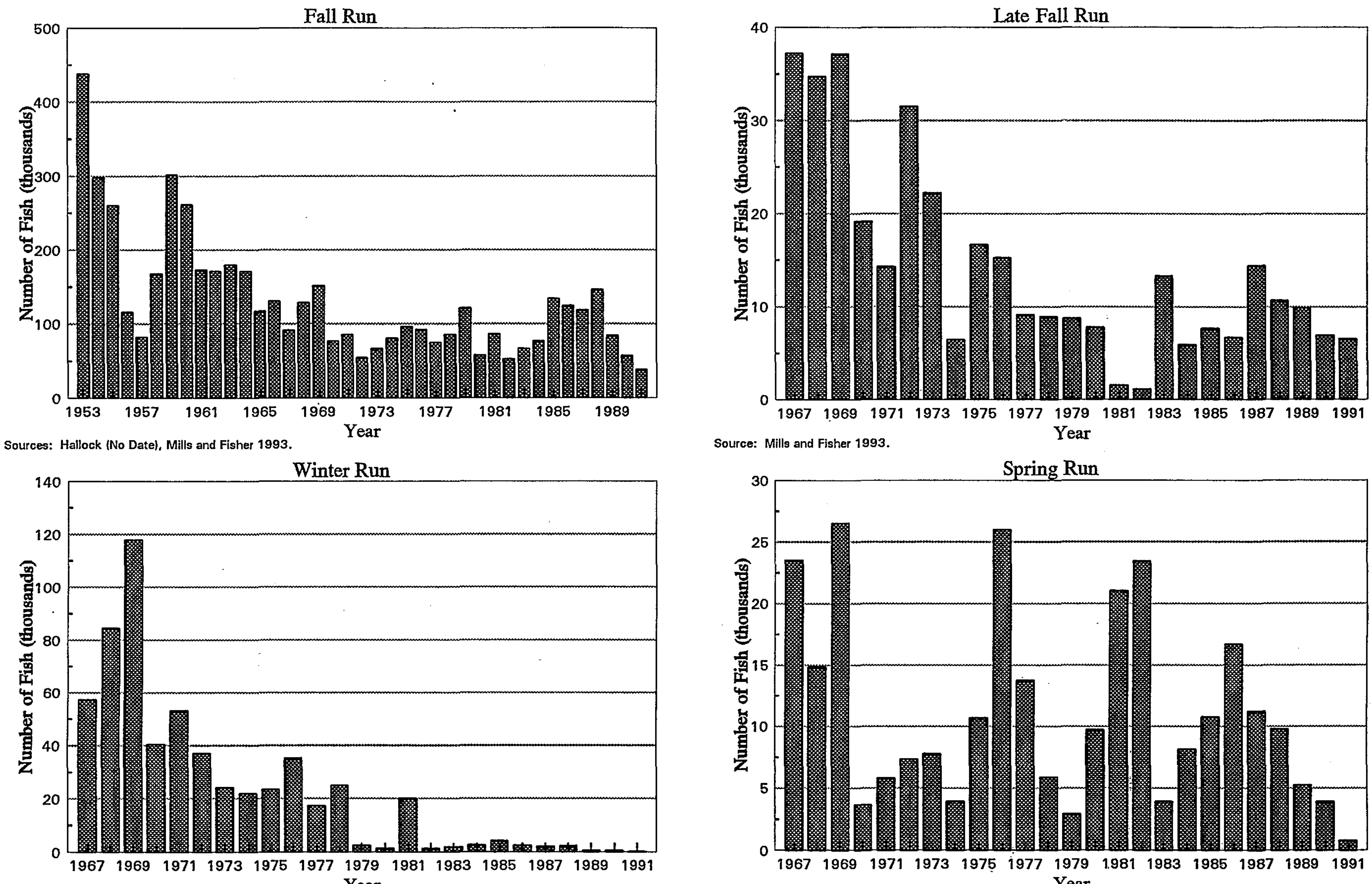
_________. 1993. Abundance and survival of juvenile chinook salmon in the Sacramento-San Joaquin estuary. (1992 Annual Progress Report.) Fishery Resource Office. Stockton, CA.

Wendt, P. G. 1987. Preliminary evaluation of factors controlling striped bass salvage loss at Skinner Fish Facility: quantity and direction of flow in the lower San Joaquin River, striped bass abundance and size, and total Delta exports. (DWR 606, Bay-Delta Hearing.) California Department of Water Resources. Sacramento, CA.

Wickwire, R. H., and D. E. Stevens. 1971. Migration and distribution of young king salmon, *Oncorhynchus tshawytscha*, in the Sacramento River near Collinsville. (Anadromous Fisheries Branch Administrative Report No. 71-4.) California Department of Fish and Game. Stockton, CA.

Table F1-1. Partial List of Fish and Invertebrate Species of the Sacramento-San Joaquin Delta

Common Name	Scientific Name
Fish	
American shad	*Alosa sapidissima*
Bigscale logperch	*Percina macrolepida*
Bullhead (2+ species)	*Ictalurus* sp.
Carp	*Cyprinus carpio*
Chameleon goby	*Tridentiger trigonocephalus*
Channel catfish	*Ictalurus punctatus*
Chinook salmon	*Oncorhynchus tshawytschya*
Crappie (2 species)	*Pomoxis* sp.
Delta smelt	*Hypomesus transpacificus*
Fathead minnow	*Pimephales promelas*
Golden shiner	*Notemigonus crysoleucas*
Goldfish	*Carassius auratus*
Green sturgeon	*Acipenser medirostris*
Hardhead	*Mylopharodon conocephalus*
Hitch	*Lavinia exilicauda*
Inland silverside	*Menidia beryllina*
Lamprey (2+ species)	*Lampetra* sp.
Largemouth bass	*Micropterus salmoides*
Longfin smelt	*Spirinchus thaleichthys*
Mosquitofish	*Gambusia affinis*
Prickly sculpin	*Cottus asper*
Sacramento sucker	*Catostomus occidentalis*
Sacramento blackfish	*Orthodon microlepidotus*
Sacramento squawfish	*Ptychocheilus grandis*
Sacramento splittail	*Pogonichthys macrolepidotus*
Smallmouth bass	*Micropterus dolomieui*
Starry flounder	*Platichthys stellatus*
Steelhead trout	*Oncorhynchus mykiss*
Striped bass	*Morone saxatilis*
Sunfish (3+ species)	*Lepomis* sp.
Threadfin shad	*Dorosoma petenense*
Threespine stickleback	*Gasterosteus aculeatus*
Tule perch	*Hysterocarpus traskii*
White sturgeon	*Acipenser transmontanus*
White catfish	*Ictalurus catus*
Yellowfin goby	*Acanthogobius flavimanus*
Invertebrates	
Bay shrimp	*Crangon franciscorum*
Mysid shrimp	*Neomysis mercedis*



Sources: Hallock (No Date), Mills and Fisher 1993.

Source: Mills and Fisher 1993.

Source: Mills and Fisher 1993.

Source: Mills and Fisher 1993.

Figure F1-1.
Chinook Salmon Spawning Escapement

DELTA WETLANDS
PROJECT EIR/EIS
Prepared by: Jones & Stokes Associates

C-061928

C-061928

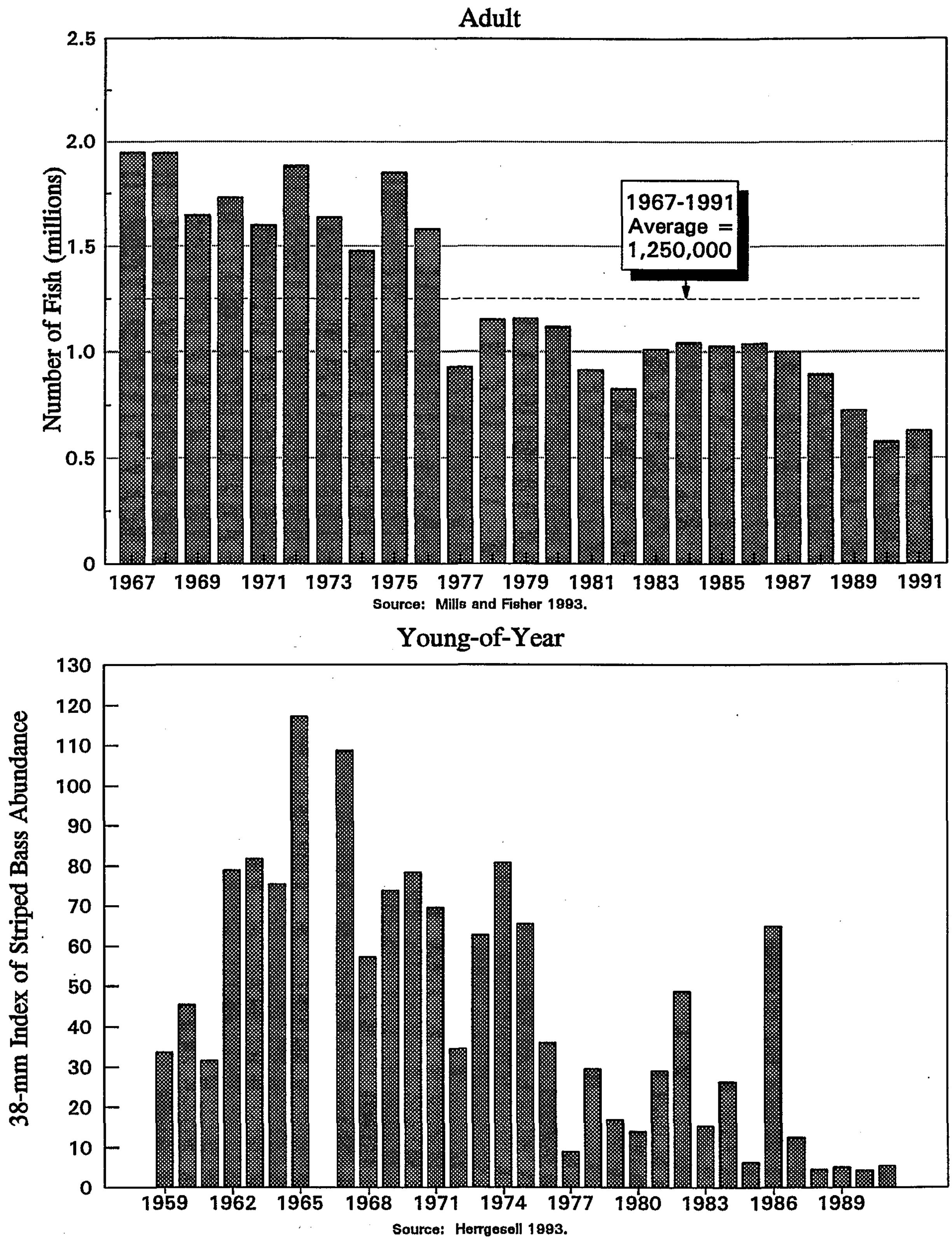
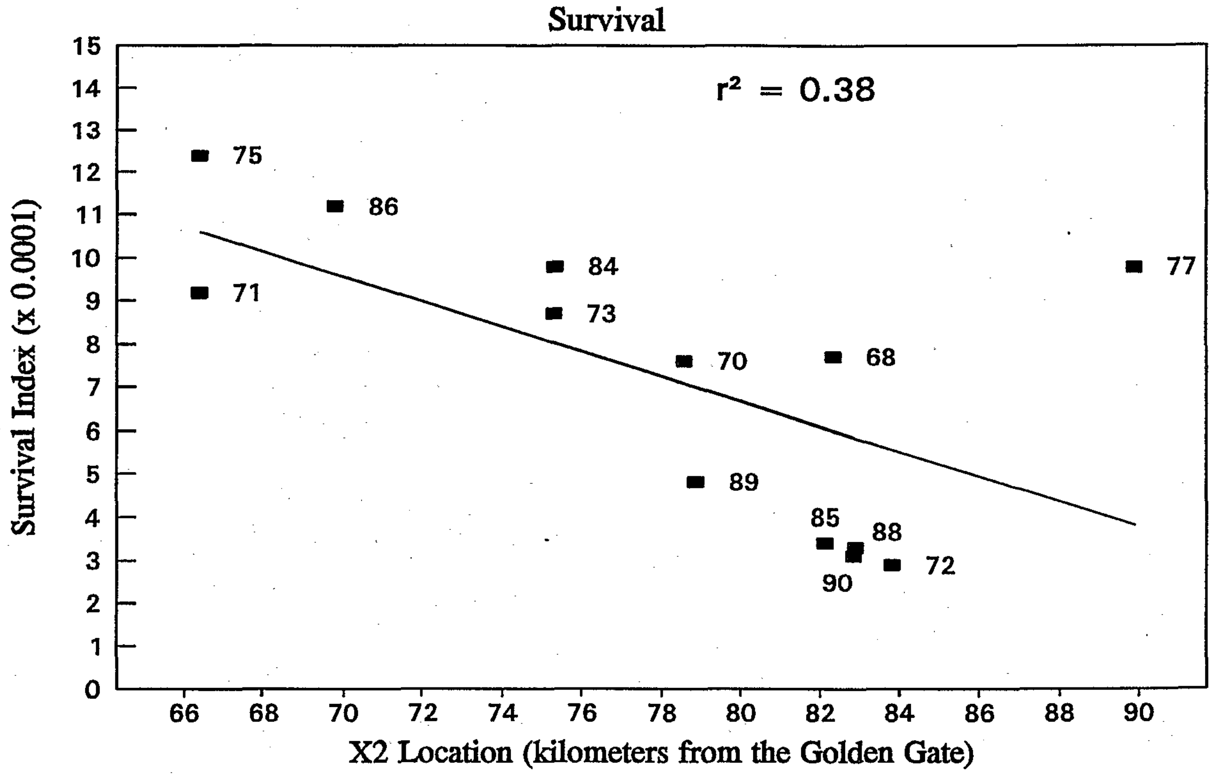
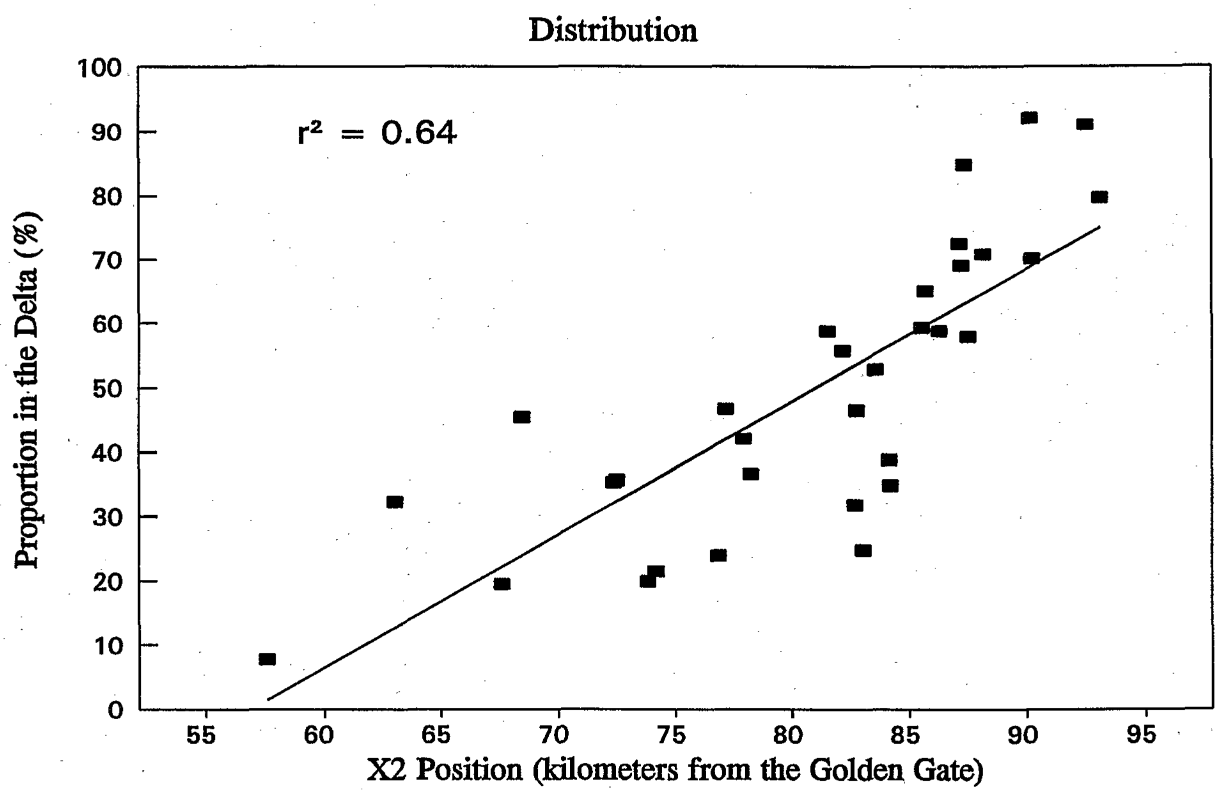


Figure F1-2.
Adult Striped Bass Abundance, 1969-1992, and Young-of-Year Striped Bass Abundance Index, 1969-1993

DELTA WETLANDS
PROJECT EIR/EIS
Prepared by: Jones & Stokes Associates



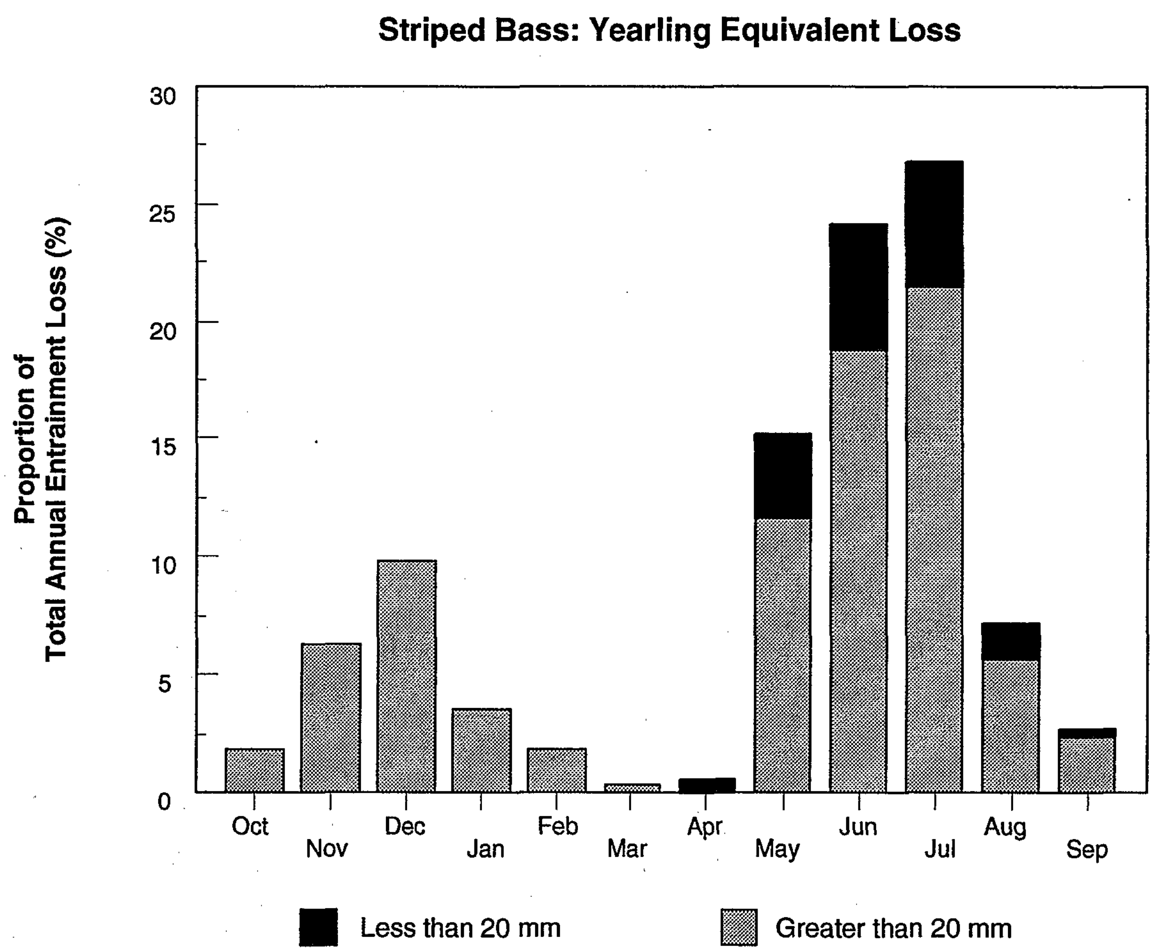
Source: California Department of Fish and Game 1992a.



Source: Herrgesell 1993.

Figure F1-3.
Relationship between Delta Outflow and Young-of-Year Striped Bass Survival and Distribution

DELTA WETLANDS
PROJECT EIR/EIS
Prepared by: Jones & Stokes Associates



Source: DFG 1992a, 1992b.

Figure F1-4.
Average Monthly Proportion of Annual Striped Bass Entrainment Loss at the SWP and CVP Fish Protection Facilities, 1979–1990